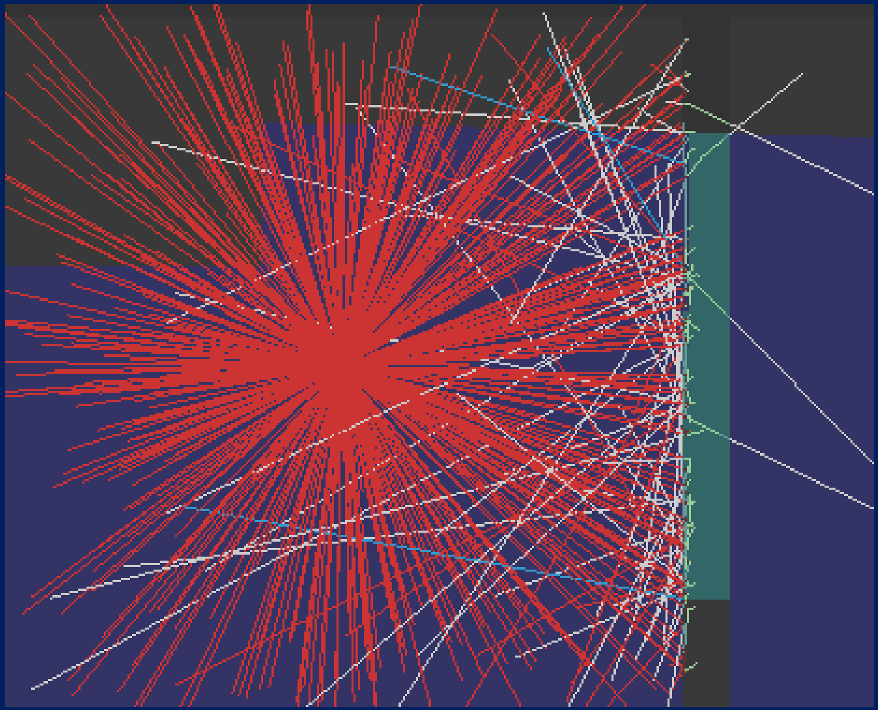
Virtual Cloud Chamber

Particle Interaction with Matter - Simulation



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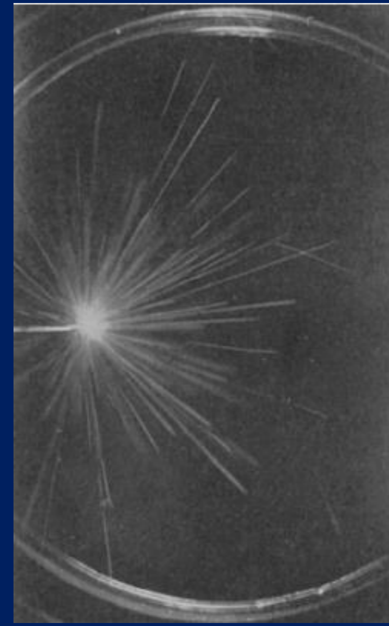
Cloud Chamber

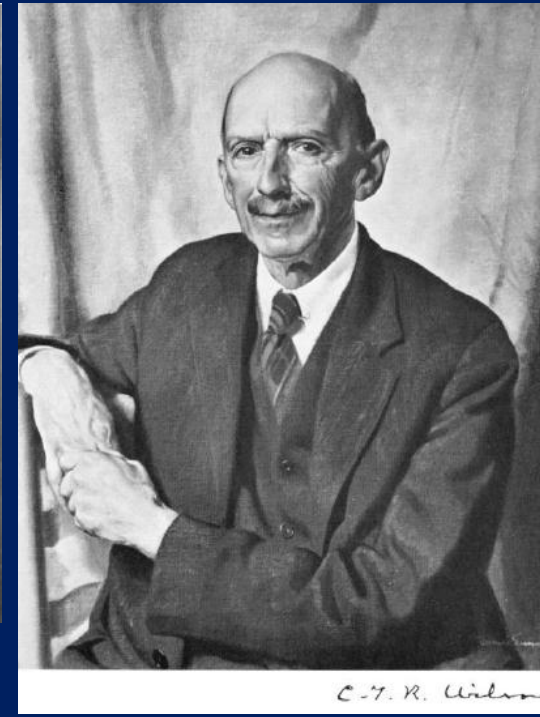
The cloud chamber was invented by the Scottish physicist Charles Thomson Rees Wilson around one hundred years ago (1911 and 1912).

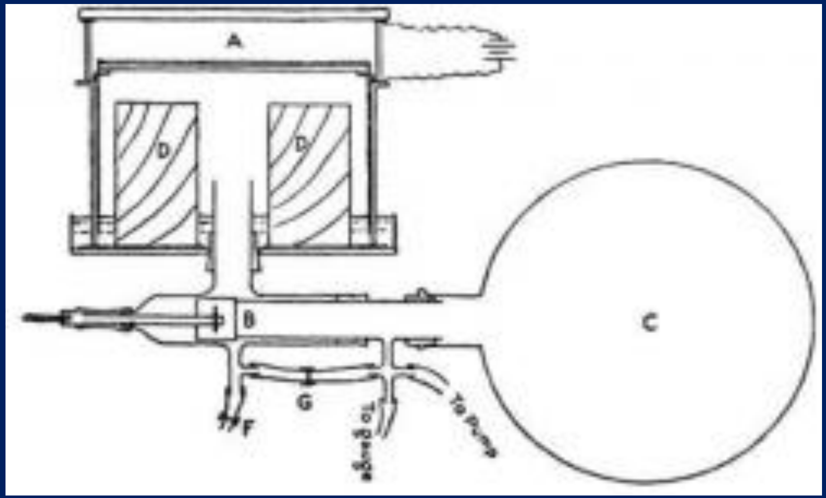
"The most original and wonderful instrument in scientific history" (E. Rutherford)

"The invention ... first revealed to the eyes of mankind the intimate details of the behaviour of the elementary particles of nature." (P. M. S. Blackett)



Tracks of alpha particles from a radium source





A rapid expansion of chamber A causes water droplets to condense on ions in the air. Radiation creates a trail of ions in the chamber. These become a track of water droplets which show up when viewed under strong illumination. The photographs show tracks of alpha particles emitted by a radium source.

Wilson's cloud chamber. A — the cloud chamber, B — a piston, C — a vacuum chamber

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Virtual Cloud Chamber:

The Virtual Cloud Chamber is an online interactive simulation tool for investigating the motion of charged particles and photons in different media. The simulation tool, which is based on the Monte Carlo GEANT 4 Engine, has been developed and integrated into the NUCLEONICA nuclear science and data portal.

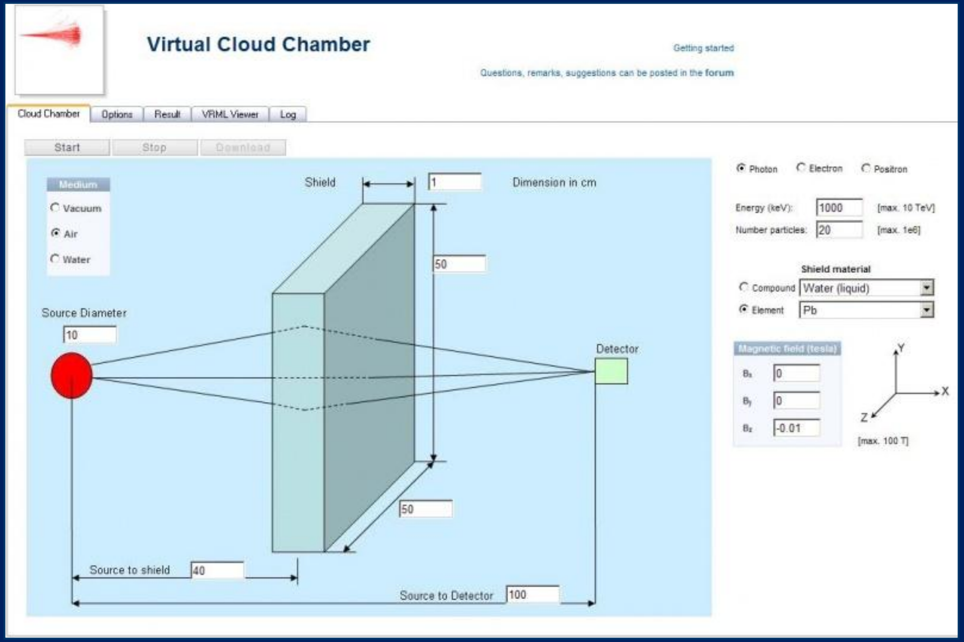
For the investigations, sources of mono-energetic particles are used. Initially the simulations are restricted to photons, electrons and positrons. To better understand the charged particles emission processes, the various energy loss mechanisms can be "switched-off" in the calculations - otherwise the range of the charged particles would be very small and almost invisible.

For photons, there the various energy loss processes - photoelectric effect, Compton scattering, and pair production - can also be switched on/off. In the images, the colour scheme - based on the colours used in the Karlsruhe Nuclide Chart - is as follows: white (photons), blue (electrons) and red (positrons).

What is Geant4?

Geant4 is the successor of GEANT3, the world-standard toolkit for HEP detector simulation.

Geant4 is one of the first successful attempt to re-design a major package of HEP software for the next generation of experiments using an Object-Oriented environment.



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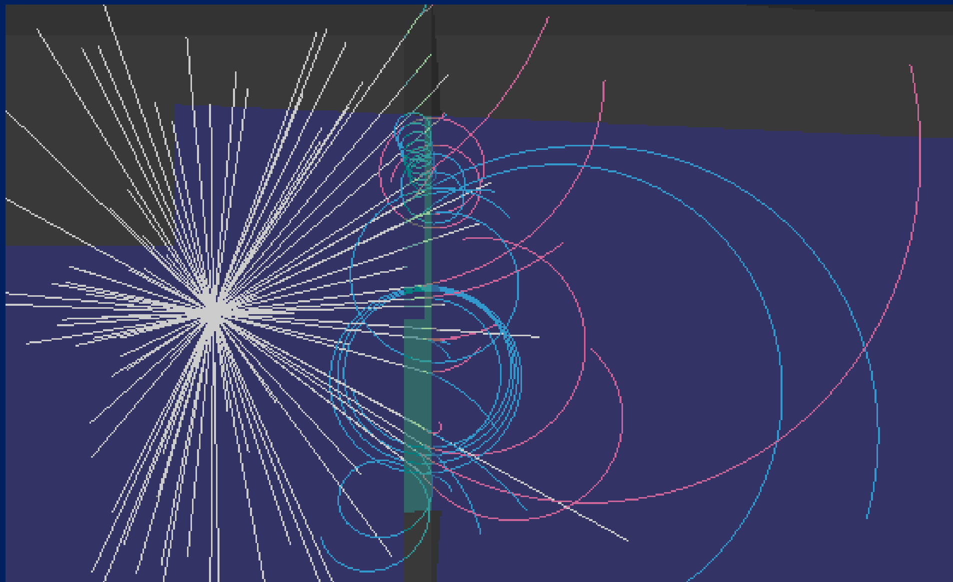
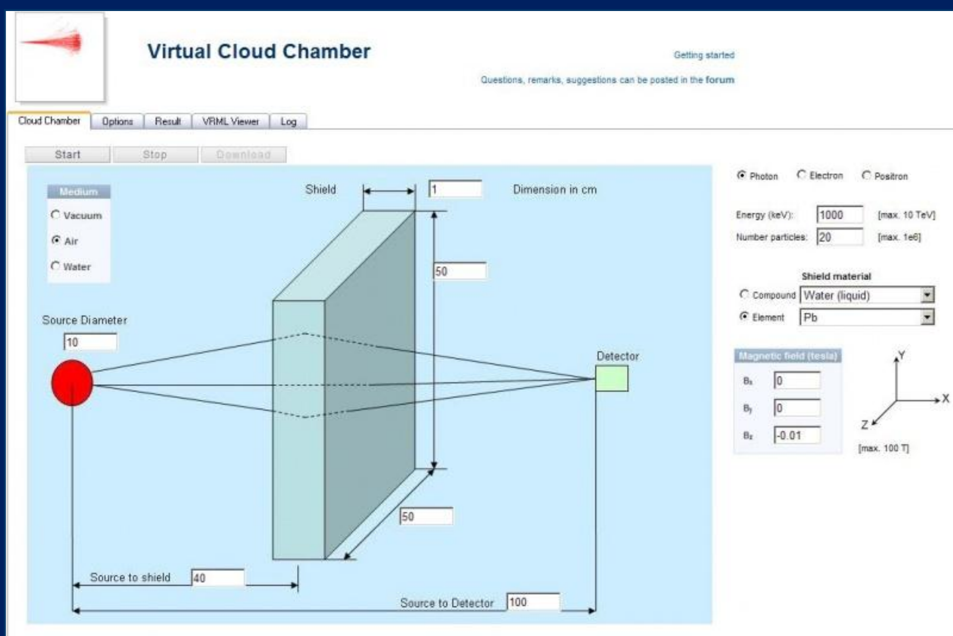
Example 1: Virtual Cloud Chamber



In this example, electron-positron pairs are created through the interaction of 10 MeV gamma photons incident on lead. By “switching off” the electron and positron energy loss mechanisms, the charged particles are seen to spiral in the applied magnetic field. Information on the energies of the electrons and positrons can be obtained from the diameter of the trajectory in the magnetic field.



Parameters used in the simulation (in addition to default values):

- Medium = Vacuum, Source diameter = 0 (point source)
- Source to shield distance = 20 cm
- Type of particle = photon, energy of particle = 10 MeV
- Number of particles = 100, Magnetic field = B_Z= -0.1 tesla
- Electron and positron interaction mechanisms (ionization, Bremsstrahlung, scattering, annihilation) all "switched off"

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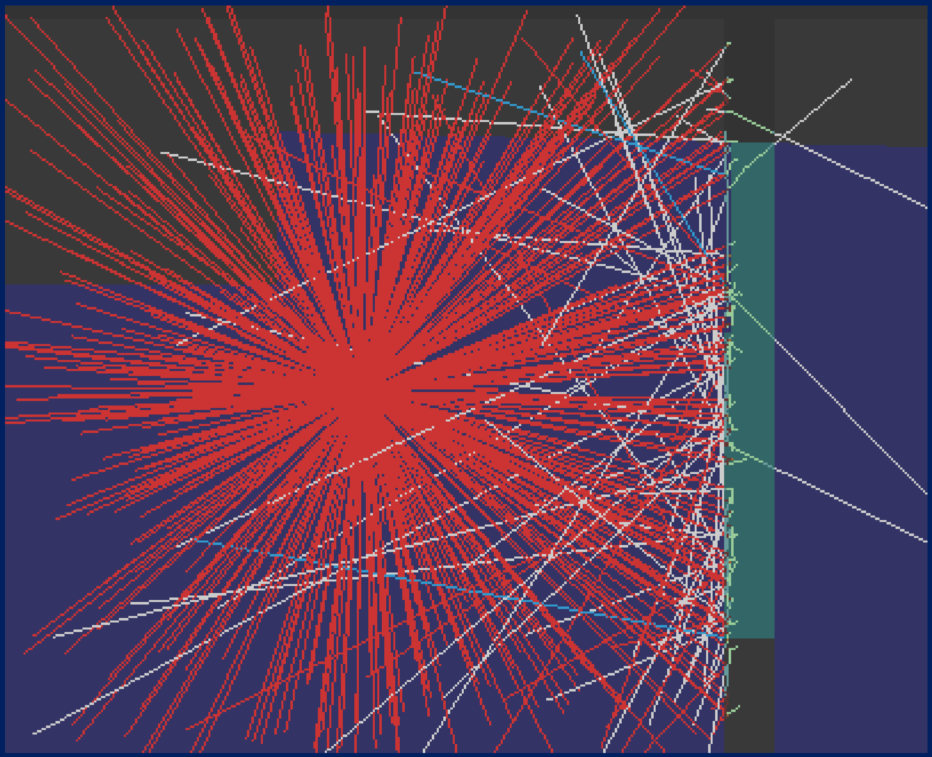
Example 2: Shielding of High Energy Radiation

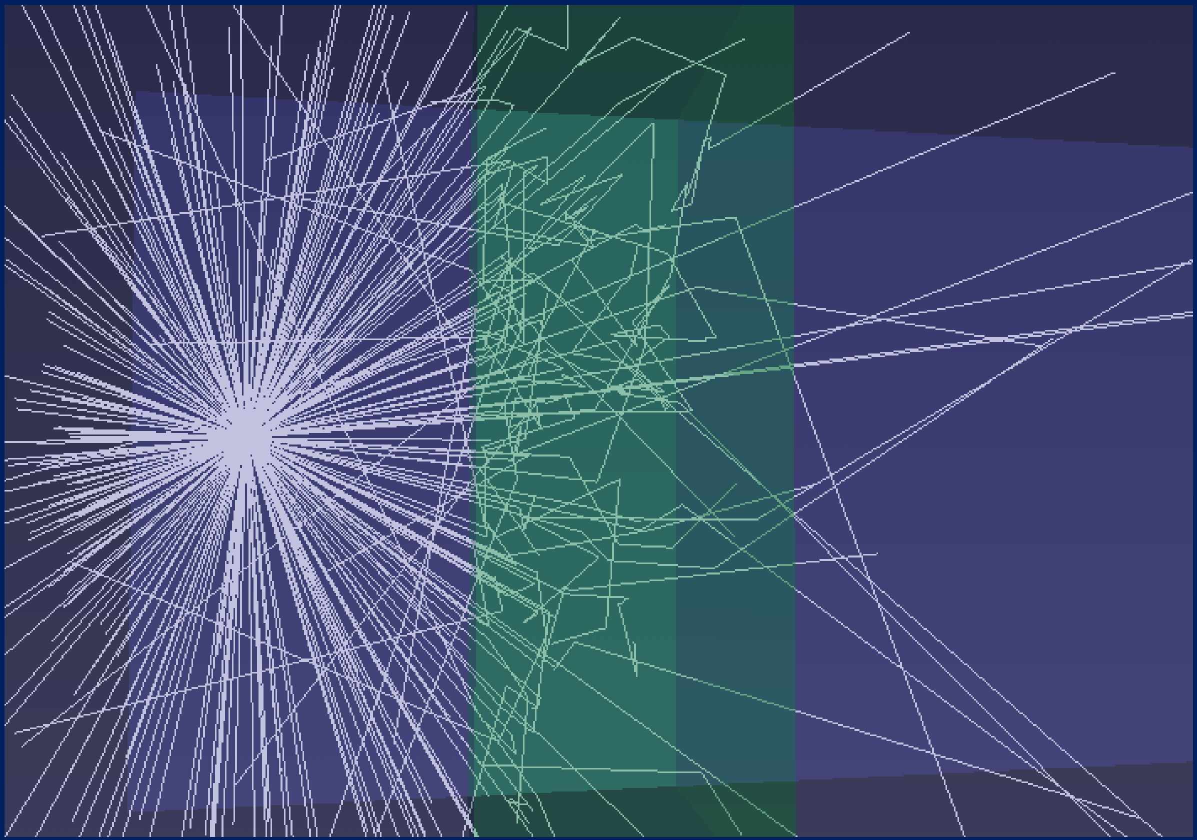


In this example, 3 MeV positrons (red) from the radioactive source are blocked by a lead shield (green). When the positrons collide with the shield, they combine with electrons (blue) to create gamma radiation (white). Only a few gamma photons pass through the shield material. In this simulation the following parameters wee used:

Parameters used in the simulation (in addition to default values):

Medium = Vacuum
Source diameter = 0 (point source)
Type of particle = positrons
Energy of particles = 3000 keV
Number of particles = 1000
Source shield distance = 20 cm
Shield thickness = 3 cm
All photon, electron and positron interaction mechanisms "switched on"

Example 3: Photon Multiple Scattering



In this example, low energy photons (energy 100 keV) are attenuated with a thick (15 cm) water shield. This combination of low energies and thick shields give rise to multiple scattering of the radiation.

Parameters used in the simulation (in addition to default values):

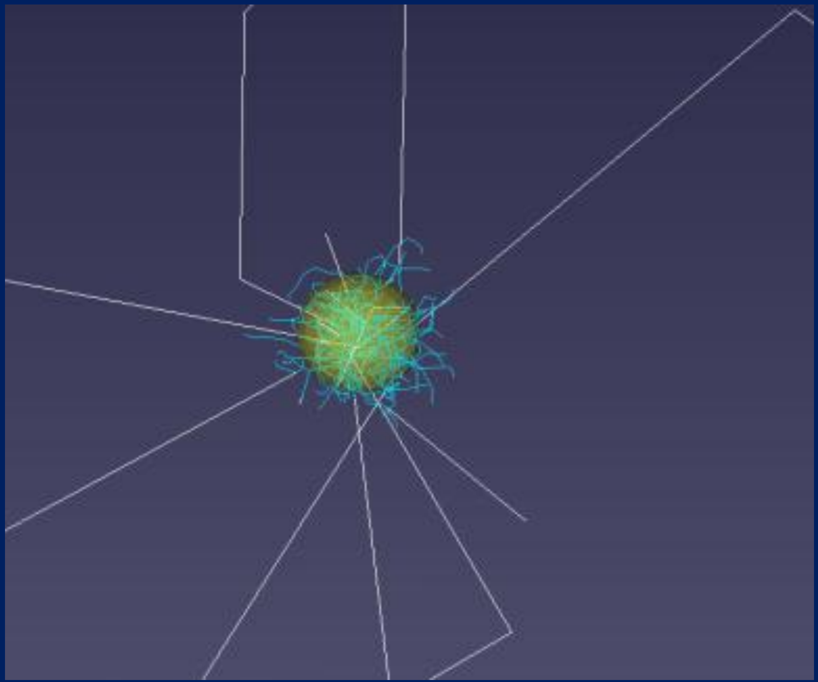
Medium = Vacuum, Source diameter = 0 (point source)

Source to shield distance = 20 cm

Type of particle = photon, energy of particle = 100 keV

Number of particles = 300, Magnetic field = B_Z= 0 tesla

Example 4: Selective Internal Radio-Therapy (SIRT)



For the simulation electrons are selected and the energy is set to 2.28 MeV (2280 keV). The simulation media selected in water (since that is very similar to tissue). The source diameter is set to 1 cm - this highlights a volume of tissue corresponding to the range of the beta particles.

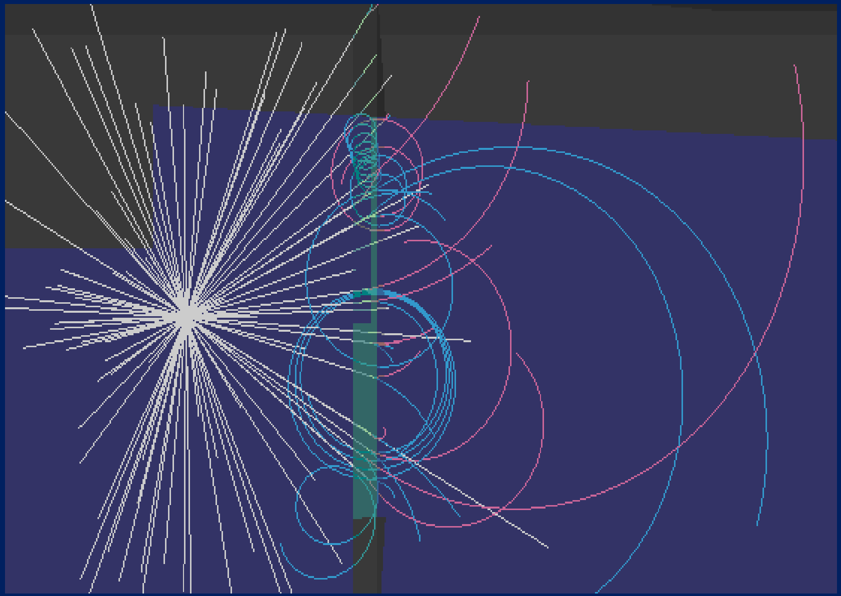
Cloud Chamber Animation – check it out!

Thanks!

Virtual Cloud Chamber: Particle Interaction with Matter (Exercises)

1.Simulate the creation of electron-positron pairs:
In this example, electron-positron pairs are created through the interaction of 10 MeV gamma photons incident on lead. By "switching off" the electron and positron energy loss mechanisms, the charged particles are seen to spiral in the applied magnetic field. Information on the energies of the electrons and positrons can be obtained from the diameter of the trajectory in the magnetic field. For this simulation, use the following parameters (in addition to default values):

Medium = Vacuum, Source diameter = 0 (point source)
Source to shield distance = 20 cm
Type of particle = photon
Energy of particle, E = 10 MeV
Number of particles = 100,
Magnetic field = B_Z= -0.1 tesla
Electron and positron interaction mechanisms (ionization, Bremsstrahlung, scattering, annihilation) all "switched off"



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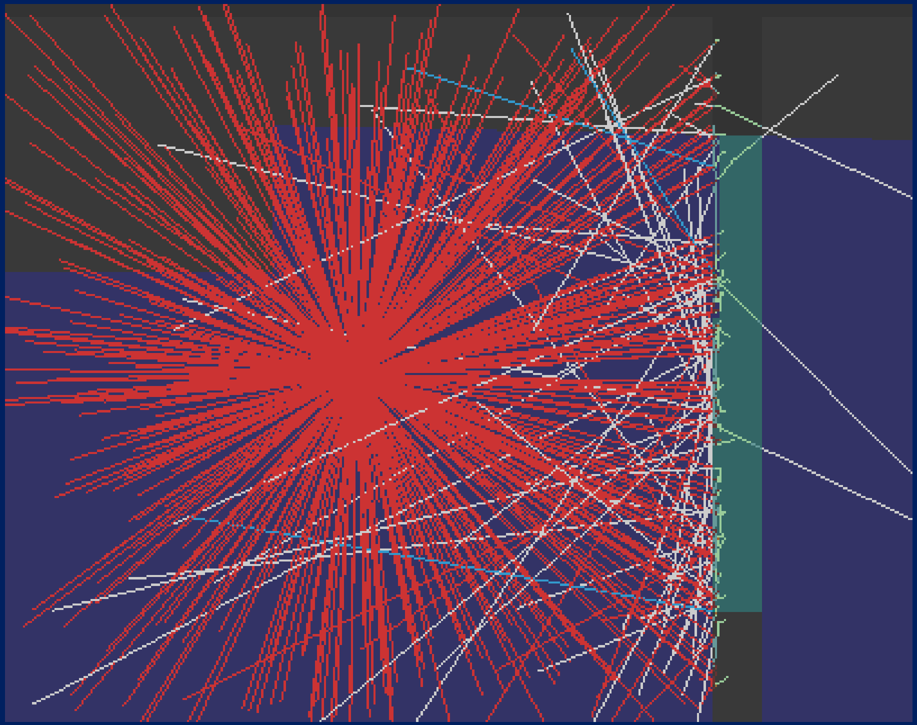
2. Simulate the shielding of high energy positrons:

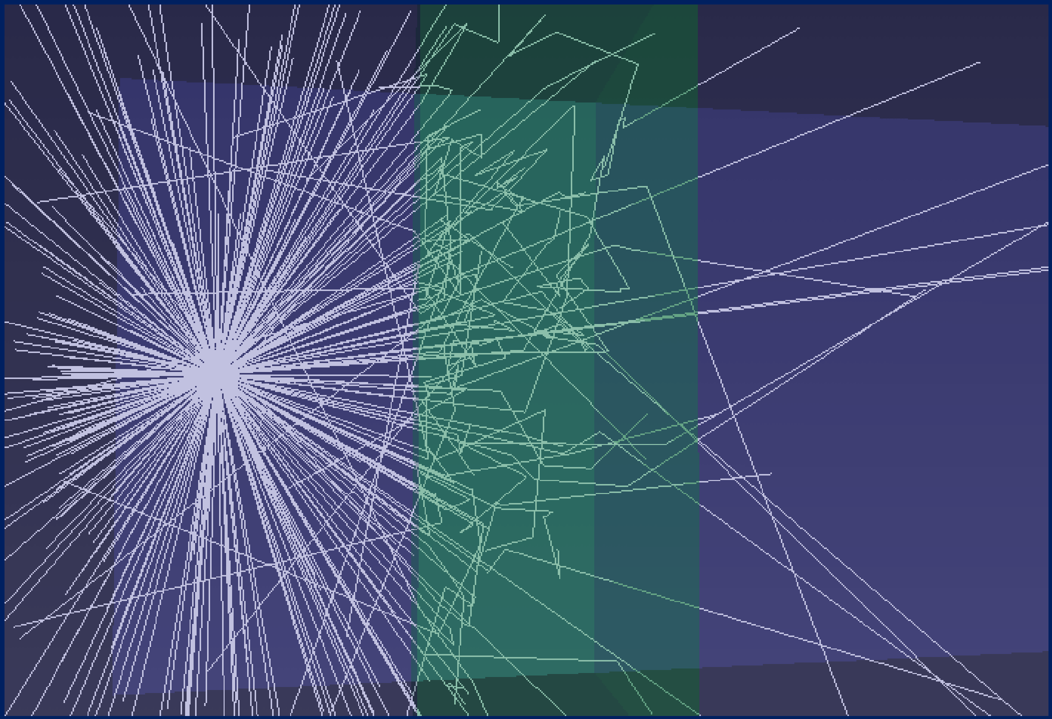
In this example, 3 MeV positrons from the radioactive source are blocked by a lead shield. When the positrons collide with the shield, they combine with electrons to create gamma radiation. Only a few gamma photons pass through the shield material. In this simulation use the following parameters:

Medium = Vacuum, Source diameter = 0 (point source)
Type of particle = positrons
Energy of particles = 3000 keV
Number of particles = 100
Source shield distance = 20 cm
Shield thickness = 3 cm
All photon, electron and positron interaction mechanisms "switched on"



3. Simulate the multiple scattering of low energy photons in water: in this example, low energy photons (energy 100 keV) are attenuated with a thick (15 cm) water shield. This combination of low energies and thick shields give rise to multiple scattering of the radiation.

Medium = Vacuum,
Source diameter = 0 (point source),
Source to shield distance = 20 cm,
Type of particle = photon,
Energy of particle = 100 keV,
Number of particles = 100,
Magnetic field = B_Z= 0 tesla



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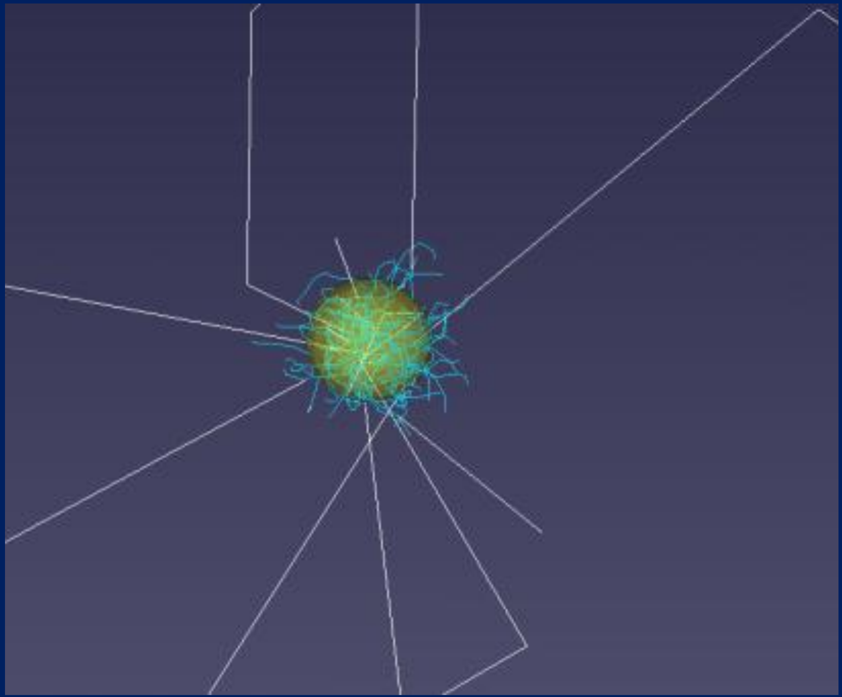
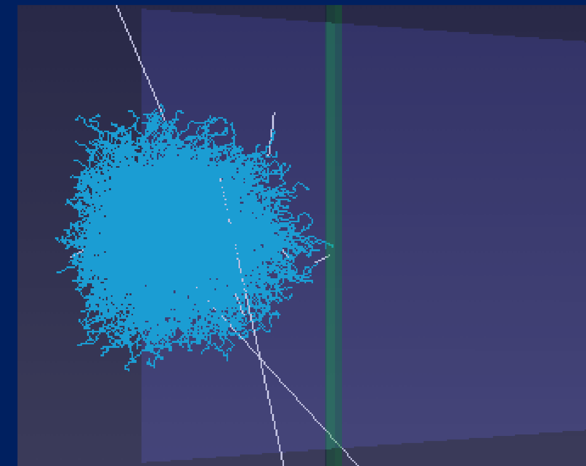
4. Simulate of Selective Internal Radio-Therapy (SIRT)

We can simulate the SIRT process using the Virtual Cloud Chamber. For the simulation electrons are selected and the energy is set to 2.28 MeV (2280 keV) corresponding to the maximum beta energy from Y-90. The simulation media selected in water (since that is very similar to tissue). The source diameter is set to 1 cm - this highlights a volume of tissue corresponding to the range of the beta particles.

Medium = Water,
Source diameter = 1 cm,
Type of particle = electron,
Energy of particle = 2280 keV
Number of particles = 100,
Magnetic field = B_Z= 0 tesla



5. What is the range of 100 keV electrons in air?



For this simulation, use the following parameters (in addition to default values):
Medium = Air, Source diameter = 0 cm (point source),
Type of particle = electron, energy of particle = 100 keV
Number of particles = 100, Magnetic field = B_Z= 0 tesla

What is the range of 100 keV positrons in air? (12.5 cm)
Why is the range of positrons in air less than that of electrons? (This is the Barkas effect. See post in the forum)

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The Barkas Effect...

According to Bethe, the stopping power of a fast charged particle penetrating through matter is proportional only to the square of its charge. In 1953 Smith and colleagues observed a small difference between ranges of positive and negative pions in emulsion. This difference between the range and stopping power of a particle and its anti-particle is called the Barkas effect and is attributed to the polarisation of the medium caused by the particle or anti-particle. Qualitatively, a positively charged particle will attract electrons and experience a greater resistance to motion. For this reason positively charged particles have a smaller range than the equivalent negative anti-particle.

More information http://www.nucleonica.net/wiki/index.php/Barkas_Effect

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